Intelligent Launch and Range Operations Virtual Test Bed (ILRO-VTB)

Jorge Bardina and T. Rajkumar
NASA Ames Research Center, Moffett Field, California, USA 94035
SAIC@ NASA Ames Research Center, Moffett Field, California, USA 94035

ABSTRACT

Intelligent Launch and Range Operations Virtual Test Bed (ILRO-VTB) is a real-time web-based command and control, communication, and intelligent simulation environment of ground-vehicle, launch and range operation activities. ILRO-VTB consists of a variety of simulation models combined with commercial and indigenous software developments (NASA Ames). It creates a hybrid software/hardware environment suitable for testing various integrated control system components of launch and range. The dynamic interactions of the integrated simulated control systems are not well understood. Insight into such systems can only be achieved through simulation/emulation. For that reason, NASA has established a VTB where we can learn the actual control and dynamics of designs for future space programs, including testing and performance evaluation. The current implementation of the VTB simulates the operations of a sub-orbital vehicle of mission, control, ground-vehicle engineering, launch and range operations. The present development of the test bed simulates the operations of Space Shuttle Vehicle (SSV) at NASA Kennedy Space Center. The test bed supports a wide variety of shuttle missions with ancillary modeling capabilities like weather forecasting, lightning tracker, toxic gas dispersion model, debris dispersion model, telemetry, trajectory modeling, ground operations, payload models and etc. To achieve the simulations, all models are linked using Common Object Request Broker Architecture (CORBA). The test bed provides opportunities for government, universities, researchers and industries to do a real time of shuttle launch in cyber space.

1. INTRODUCTION

Intelligent Launch and Range operations Virtual Test Bed (ILRO-VTB) is software for prototyping of large-scale, multi-technical dynamic systems. It allows proof-testing of new designs prior to real-time hardware construction. These different systems are modeled using commercial and indigenous developments (NASA Ames) that create a hybrid software/hardware environment suitable for testing various integrated control system components of launch and range. A purpose of the VTB is to combine all the heterogeneous models into one simulation environment. An additional objective is to improve the state of the art for building simulation tools by integrating traditionally stand-alone simulation tools into the system environment. The dynamic interactions of integrated control systems in a virtual building are not well understood.

With the increasing pressure to build systems to integrate complex operations with more controls and services, there is a desperate need to test and evaluate the complex interactions likely to occur under normal and adverse (i.e. emergency) conditions. These tasks cannot be accomplished using real systems because of the complexity involved and the need to maintain a comfortable and safe environment at all times. They can only be done through simulation/emulation and the establishment of a Virtual Test Bed where we can learn the actual control of launch programs and evaluate their performances. For that reason, we are developing the VTB to simulate the mission, control, ground-vehicle, launch and range operations[1,2]. The present development of the test bed simulates the operations of the Space Shuttle Vehicle (SSV) at NASA Kennedy Space Center. This concept will reduce the cost of shuttle missions and allow evaluation of launch performance in advance. The technologies and modeling tools used in the test bed are discussed in detail in the following sections.

2. TEST BED CONCEPT

The operations test bed is a full-scale virtual operations control center for simulating launch, range and mission control concepts. The test bed supports a wide variety of shuttle missions with ancillary modeling capabilities like weather forecast, lightning tracker, toxic gas dispersion model, debris dispersion model, telemetry data and models, trajectory modeling, ground operations, and payload models. The test bed framework is highly robust, scalable and allows rapid integration of models, including unlimited cross-platform models. To achieve the integration of the simulations, all the models are linked using Common Object Request Broker Architecture (CORBA)[3,7,12,13]. The proposed test bed would provide opportunities for government, universities, researchers and industries to do a real time of shuttle launch in cyber space. In summary, the test bed is a facility for experimenting with operational concepts of a shuttle launch in a controlled environment.

ILRO VTB architecture is based on the parallel simulation of the mission, control, ground-vehicle, launch and range operations in a secured web-based online environment, as it is shown in figure 1.

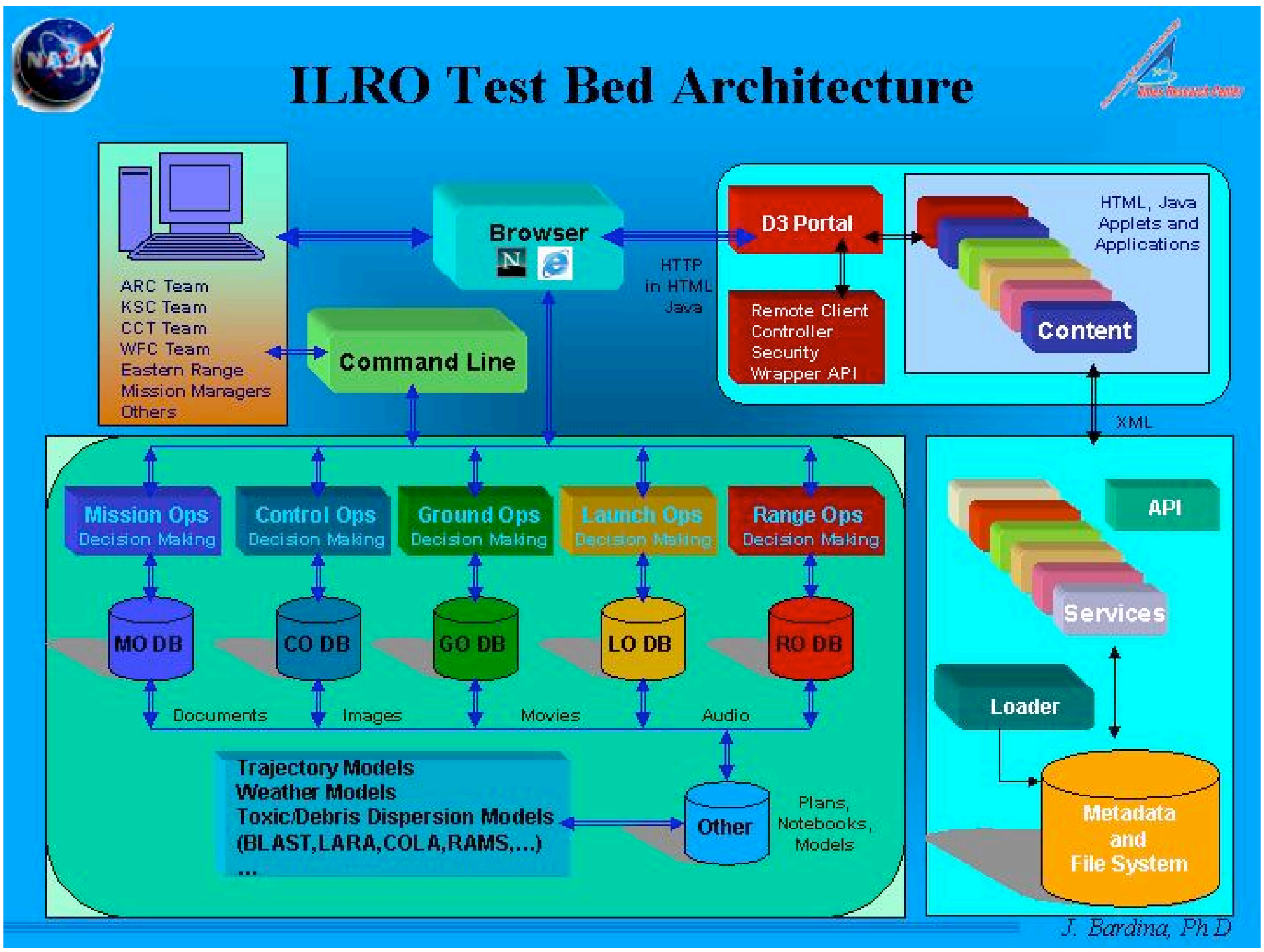

Figure 1. Basic Architecture of ILRO-VTB

The simulation requirements of the ILRO-VTB will be used as the starting point for developing a new generation of simulation tools, ones that can more accurately predict the complex interactions of shuttle launch under a variety of operating conditions. The maturity of information and space technology brings a new era of simulation techniques of shuttle launch in a distributed environment. CORBA is a specification for distributed object-based computing that enables clients and servers to communicate (Figure 2). CORBA is explicitly platform and language independent. The significant advantage of this technology forms the basis of communication and supporting foundation for ILRO-VTB. The basic CORBA task is to integrate many different software programs, written in many different programming languages and running on different machines, into a single distributed application. To do this, CORBA needs to have a way to define how these programs communicate with each other, a way to define how values are passed between programs and a well-defined (at the level of bits) wire protocol. CORBA development cycle will involve defining interfaces to servers and value objects, after which stubs and skeletons will be generated, and the client and server programs will be written.

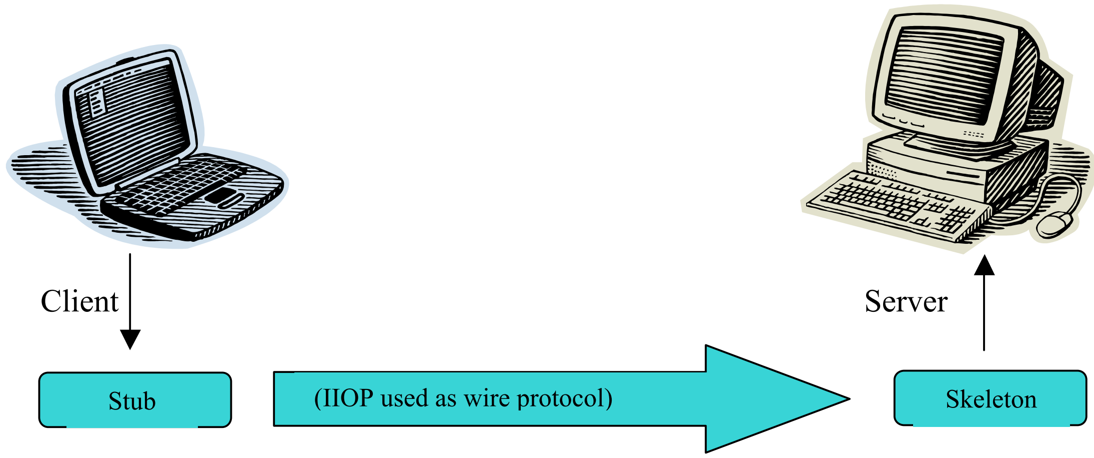

Figure 2. Basic CORBA architecture

In the VTB, the Interface Definition language (IDL)[3] serves as glue between different programs and languages. Based on IDL's rich set of data types, and its ability to define value objects, IIOP is used as the formal mapping from IDL interfaces and data types to streams data over the wire in much the same way that Remote Method Invocation (RMI) uses serialization to define a wire format. The translation from IDL to programming languages is based on CORBA. The IDL data types need to be mapped to programming language data types. Since CORBA has no distributed garbage collection mechanism, RMI-IIOP[12] is used to program RMI interfaces combining Java with CORBA, and IIOP is used as the underlying transport. In figure 3 the top section represents the RMI (Java Remote method protocol JRMP), the middle section the RMI-IIOP model, and the bottom section the CORBA model. RMI-IIOP supports both JRMP and IIOP protocols. A server binary (i.e., a class file) created using RMI-IIOP APIs can be exported as either JRMP or IIOP. The semantics of CORBA objects defined in IDL are a superset of those of RMI-IIOP objects.

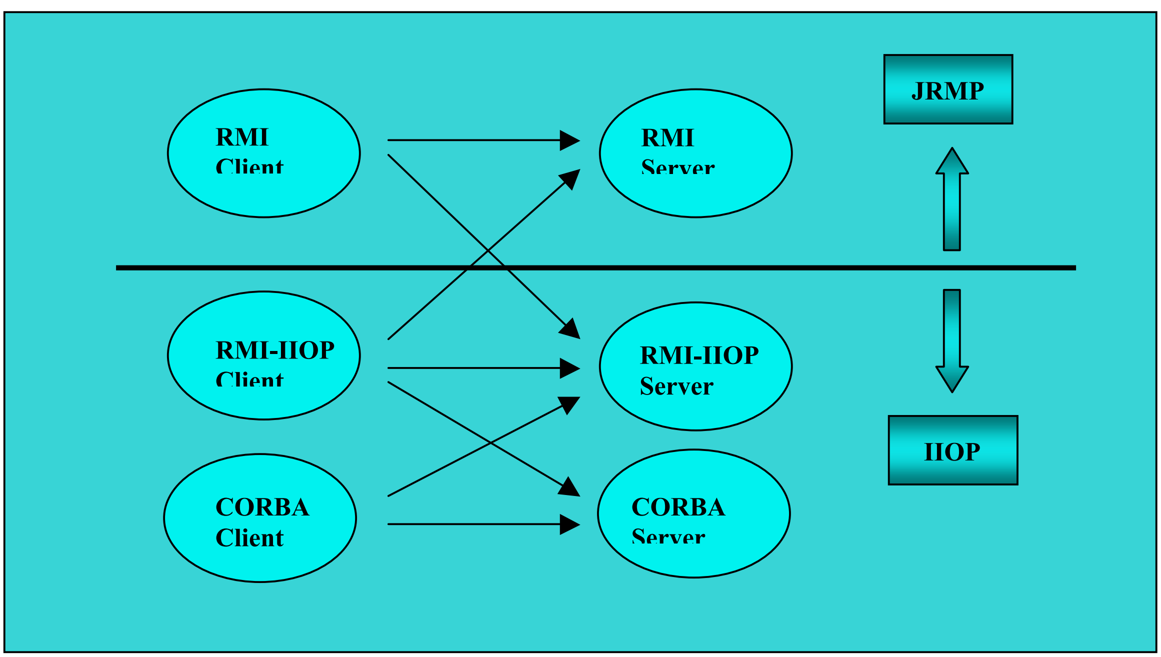

Figure 3. RMI over IIOP

Figure 4 shows an schematic of the development procedures for both RMI-IIOP servers and clients. Just as in RMI (JRMP), a distributed object's definition is its RMI java interface. A difference is made by using the –iiop parameter of the rmic compiler. Under this option, rmic generates the stubs and tie that support of the IIOP protocol. Without this –iiop option, rmic generates a stub and skeleton for the JRMP protocol. Using java IDL, it is possible to access diverse sets of models as CORBA objects from java. RMI-IIOP combines RMI's ease of use with CORBA's interoperability and mission critical infrastructure. The ability to use IIOP and generate IDL allows seamless integration into a CORBA infrastructure of legacy as well as new models. By bringing java and CORBA together, the system enables a strong foundation for constructing ILRO-VTB with robustness and seamless integration of the models.

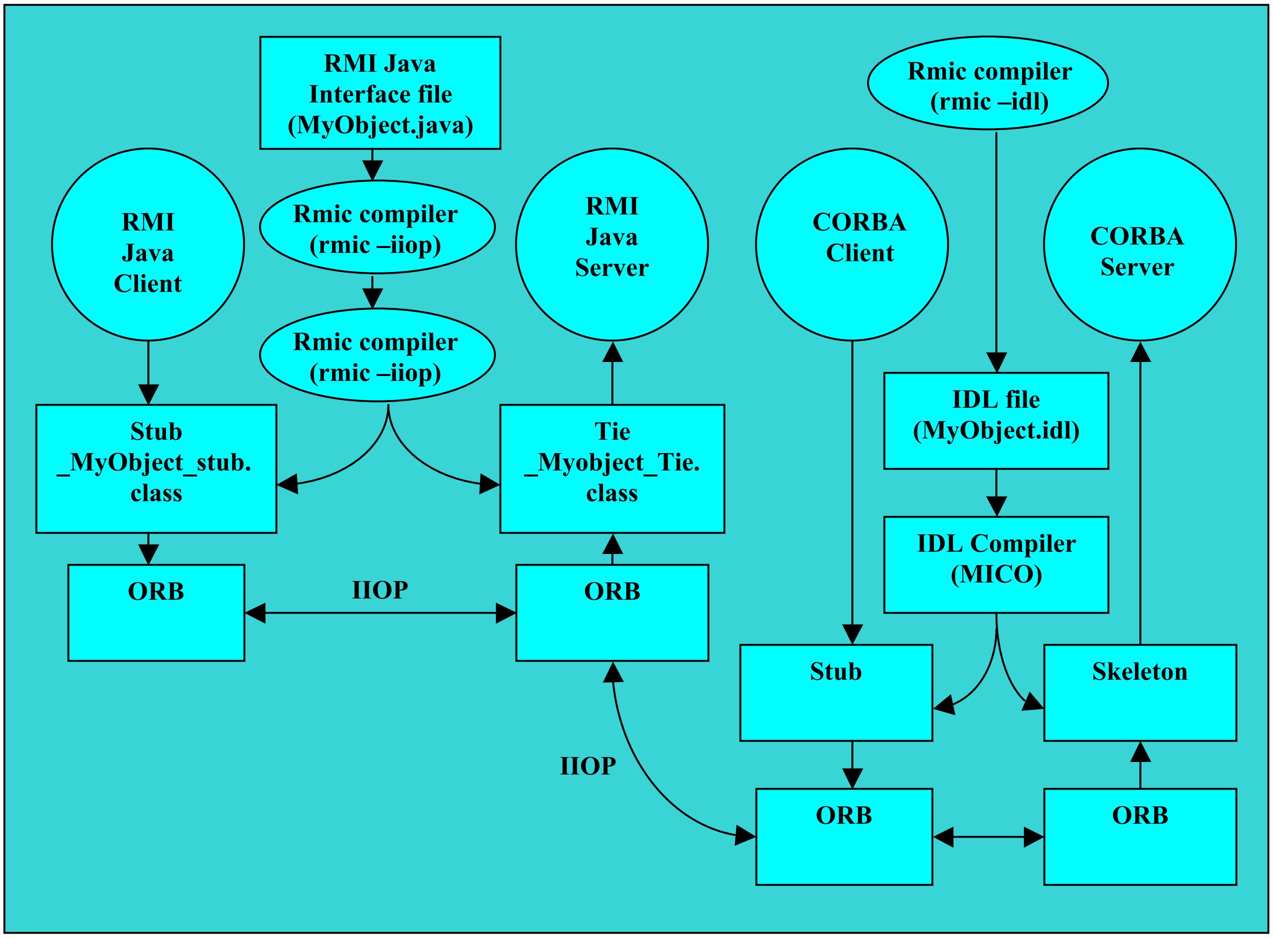

Figure 4. RMI-IIOP development procedure

3. COMPONENTS IN VIRTUAL TEST BED

The virtual test bed evolves from the operations of the sub-orbital vehicle shown in figure 5. Command and Control supervises the ground-vehicle, launch and range operations. In the virtual test bed, the shuttle launch team is organized into three groups, according to major functional responsibility. All three groups report to the shuttle launch director, who has overall technical and safety responsibility for the countdown. The prime launch team is responsible for test, checkout and monitoring of the flight hardware and ground support equipment to ensure that all system parameters meet the criteria to commit the vehicle to launch. The engineering support team has a similar composition and organization to that of launch team, but is not directly responsible for system management. This team monitors system only with no command capability or responsibility. The senior managers comprise the mission management team reporting any issues that may affect the safety or success of the countdown or mission.

Three teams are handling millions of events before and after shuttle launch. In the virtual test bed, major events and launch commit criteria models are adopted to simulate shuttle launch.

There are 44 separate initial categories of models available in launch commit criteria. Out of these 44 categories, 6 categories are currently implemented in the Test Bed: Weather rules (WEA), eastern test range safety (ETR), Hold/cutoff guidelines (HOLD), payloads (PAY), Ground support equipment (GSE), Merrit Island launch area (MILA). The models are obtained from NASA KSC and integrated into the ILRO-VTB. Five independent servers support the test bed. Each server is assigned to particular area of expertise. In some cases, two domain areas are deployed through a single server. These five servers are supported by RMI-IIOP communication. The gateway to ILRO-VTB is implemented through the DARWIN[5,6] portal, to make use of its built-in high security encryption to ensure privacy and security.

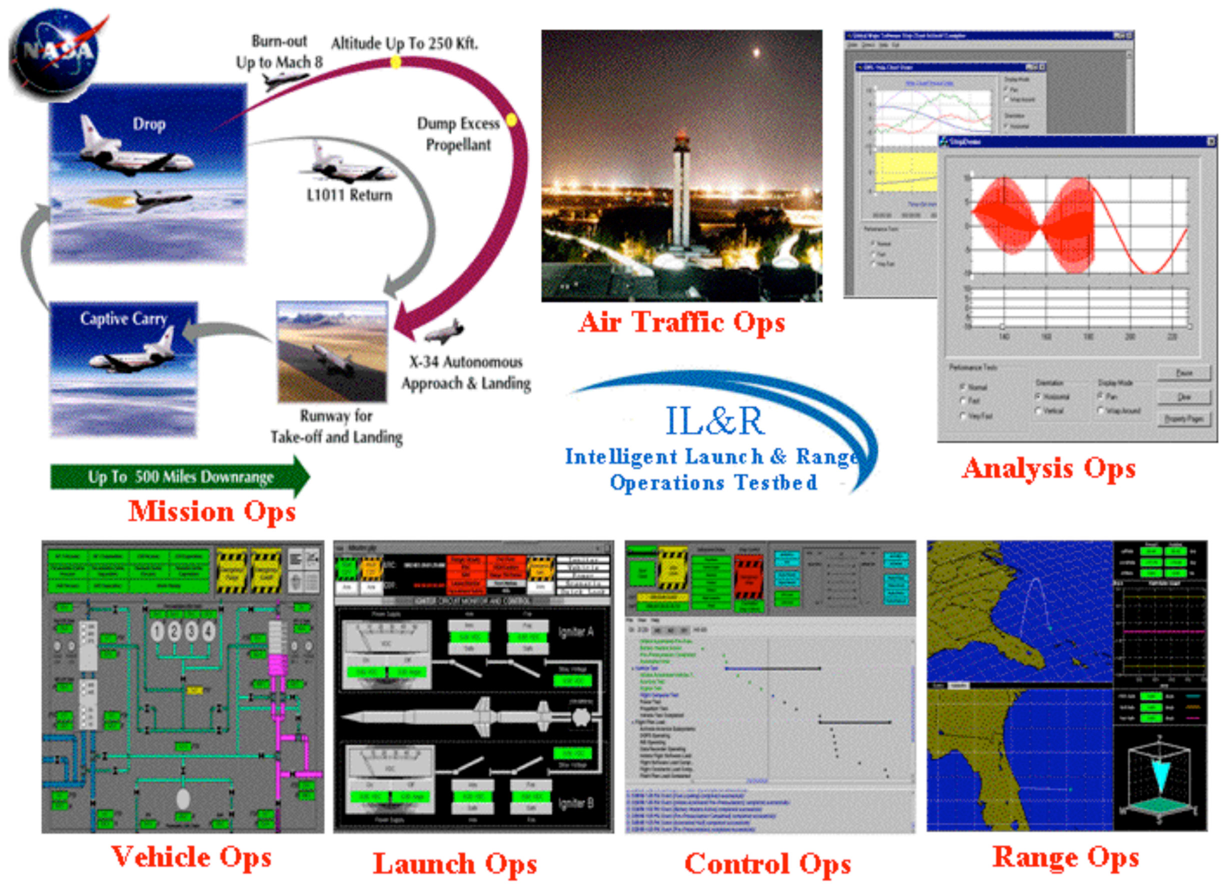

Figure 5. Sub-Orbital Vehicle Test Bed

Weather Model: Weather data generated by the Rapid Update Cycle version 2 (RUC-2)[15] available on an hourly basis from the National center for environmental prediction will be integrated into test bed. RUC-2 provides short-range forecasts of wind and temperature profiles (along with other atmospheric and surface parameters) over various time intervals ranging from 1 hr to 12 hrs. The horizontal resolution of the RUC-2 grid is 40 km, and the vertical resolution includes 37 isobaric levels corresponding to pressure altitudes ranging approximately from sea level to 53,000 ft. The National Weather Service has a central collection of WSR-88D radar products. NEXRAD (Next Generation Radar) obtains weather information (precipitation and wind) based upon returned energy. The radar emits a burst of energy (green). If the energy strikes an object (rain drop, bug, bird, etc), the energy is scattered in all directions (blue). A small fraction of that scattered energy is directed back toward the radar. Weather surveillance radars such as the WSR-88D can detect most precipitation within approximately 80 nautical miles (nm) of the radar, and intense rain or snow within approximately 140 nm. However, light rain, light snow, or drizzle from shallow cloud weather systems is not necessarily detected. WSR-88D data products are also integrated into virtual test bed to study weather around landing and launch sites.

Lightning Tracker Model: The National Center for Atmospheric Research (NCAR) has several tracking related models: (1) Tracking Radar Echoes by Correlation (TREC), (2) Thunderstorm Identification, Tracking, Analysis, and Now casting (TITAN), (3) Convergence Line Detection (COLIDE), and (4) the Automated Thunderstorm Now casting system (Auto-now caster). TREC is a correlation tracker for clear-air echoes. TITAN, is a storm centroid tracker with predictive capability based on trends. It consists of two versions: a real-time algorithm for clear-air convergence line detection and an algorithm for precipitation echo extrapolation. COLIDE is a boundary detection product that is similar to MIGFA. The Auto-now caster is an expert system that currently utilizes TREC, TITAN, COLIDE and MIGFA to provide a 30 minute forecast of thunderstorm initiation. The Techniques Development Laboratory's (TDL) Thunderstorm Product developed in support of the Advanced Weather Interactive Processing System (AWIPS,) uses VIL, GOES-Next imagery, ground flash rates from the National Lightning Detection Network (NLDN), and Automated Surface Observing System (ASOS) observations to determine thunderstorm threats for airports. Initially a simple lightning tracker model can be implemented and further it can be enhanced during developments of test bed. Weather model and lightning tracker model will be deployed through first server of ILRO-VTB test bed.

Air Traffic Models: FACET[11] (Future Air Traffic Management Concepts and Evaluation Tool) is a simulation and analysis tool being developed at NASA Ames Research Center. The purpose of FACET is to provide a simulation environment for exploration, development and evaluation of advanced air traffic management concepts. FACET models system-wide en route air space operations over the contiguous United States. The architecture of FACET strikes an appropriate balance between flexibility and fidelity. This feature enables FACET to model air space operations at the US national level and process over 5000 aircraft on any wide variety of operating systems. It will be integrated into test bed to analyze air traffic in US air space with launch vehicle data.

Shuttle Trajectory Model: The output of a flight path prediction model would be a nominal trajectory flight plan and potentially abort trajectory files. During flight, the model computes present position, determines potential abort trajectories and predicts the rest of the path. Sub-level models include vehicle aerodynamic and thrust models that characterize the vehicle and composite force models. The composite effect of forces provides a much higher fidelity model than traditional individual models.

Toxic Gas Dispersion Model*:* REEDM[4] (Rocket Exhaust Effluent Diffusion Model) analyses were performed to characterize the chemical emissions associated with launch vehicle catastrophic failures. Meteorological conditions at the time of launch are a critical factor in the behavior of rocket exhaust buoyant cloud rise and subsequent downwind transport and diffusion. The most important factor is the vertical temperature profile of the lower atmosphere, followed in importance by the wind speed and direction vertical profiles. As with classical air pollution meteorology, the presence of stable air layers determines whether or not emissions will get trapped near the ground surface or will mix through a deeper, well-ventilated air volume. REEDM treats the stable air layer associated with a temperature inversion as a capping layer that blocks transport of gases across the layer. Thus the presence of a temperature inversion and its proximity to the thermally stabilized rocket exhaust cloud are significant parameters affecting ground level concentrations of rocket exhaust gases. Gravitational settling as well as atmospheric turbulence influences rocket exhaust aluminum oxide particulates. REEDM, however, is a Gaussian dispersion model, which means it requires a single average wind speed and wind direction in the mathematical algorithm that computes the downwind concentrations. REEDM uses a weighted averaging scheme to compute the average transport wind speed and direction.

CALPUFF[9,10] is a multi-layer, multi-species, non-steady state puff dispersion model that can simulate the effects of time and space varying meteorological conditions on pollutant transport, transformation and removal. CALPUFF can use three-dimensional meteorological fields computed by CALMET model, or simple, single station winds in a format consistent with the meteorological files used to drive the ISC3[16] or the CTDM steady-state Gaussian models. CALPUFF contains algorithms for near-source effects such as building downwash, transitional plume rise, partial plume penetration and sub grid scale terrain interactions as well as longer range effects such as pollutant removal (wet scavenging or dry deposition), chemical transformation, vertical wind shear and over water transport. Most of the algorithms contain options to treat the physical processes at different levels of detail, depending on the model application. Above two models will be integrated into test bed to study the impact of toxic gas dispersion.

LATRA[8,14] The US Air force is developing a computer model, called the Launch Area Toxic Risk Analysis (LATRA) model, to assist the commanders at Cape Canaveral and Vandenberg Air Force Base in determining when it is safe to launch rocket vehicles. The LATRA model is designed to estimate the probabilities of mild and serious health effects from exposing specified human subpopulations to estimated concentrations of specific rocket emissions. It contains two major components (i) a dispersion model that predicts downwind exposure concentrations. (ii) exposure-response functions (ERFs) that relate the estimated exposure concentrations to expected health effects. The LATRA model operates as a Monte Carlo simulation. A binomial model is used to simulate the variance (uncertainty) associated with the predicted number of people affected. The potential for combined effects of exposure to more than one compound is estimated by developing joint probabilities of effect from the individual toxicants probabilities of effect. The LATRA models estimates of the total number of people at risk of health effects from a launch are based on (i) the risks associated with a normal launch. (ii) the probability of a normal launch (iii) the risks associated with a catastrophic abort, and (iv) the probability of a catastrophic abort.

Debris Dispersion Modeling: A debris fragment is considered to be potentially lethal to an aircraft if it is capable of producing sufficient damage to cause loss of life or necessitate emergency response by the crew to avoid a catastrophic consequence. Two ways that debris can be hazardous to aircraft are: (a) fragment penetration of a critical aircraft structure or the windshield and (b) fragment ingestion by an engine. The FATEPEN2 model is used to determine/predict the smallest solid cylindrical fragments that could penetrate a front spar or a wind shield. This model will be integrated to study the impact of debris dispersion modeling.

Overall ILRO test bed will have various modeling tools and visualization techniques for rapid study of shuttle launch and range. The above models will be integrated in the first phase of the project. Ground operations and payload models from NASA KSC will be integrated. In addition to that, VTBL (Virtual test bed language) can be created for rapid custom modeling of test bed to test different categories and scenarios.

4. CONCLUSION

The ILRO-VTB provides an ideal simulation environment to engage research capacity from simple to complex heterogeneous systems in space technology. This simulation test bed uses the latest information technology to bring a real time simulation on-line using the web. Secure remote access capability would decrease the number of personnel required on site to support the test simulation. Modeling and monitoring human performance metrics are key elements of the Test Bed. Developing models for analyzing ground operations, trajectory analysis, and flight operations in an integrated fashion will give in-depth understanding of the process for mission planners, safety analysts and ground controllers. ILRO-VTB is the tool and the process to integrate information technology for analyzing end-to-end shuttle and space launch simulations.

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